Economic Viability of Floating In-Pond Raceway Systems for Commercial Hybrid Catfish Production

by

George Coates Fullerton

A thesis submitted to the Graduate Faculty of
Auburn University
In partial fulfillment of the
Requirements for the Degree of
Master of Science

Auburn, Alabama
August 6, 2016

Keywords: Raceway, Hybrid Catfish, Production, Economics

Approved by

Jesse Chappell, Chair, Associate Professor, School of Fisheries, Aquaculture and Aquatic Sciences
Terry R. Hanson, Professor, School of Fisheries, Aquaculture and Aquatic Sciences
Eric Peatman, Associate Professor, School of Fisheries, Aquaculture and Aquatic Sciences

Abstract

An in-pond raceway (IPRS) production trial was conducted in Dallas County, AL from January to November 2015. The goal of this work was to see how this new technology would behave in a commercial catfish farm setting and if previously found results of improved feed conversion, survival and production using this system would apply. If so, this could improve the efficiency of the catfish industry in the Southeastern United States. The objectives of this study was to evaluate the production and economic characteristics of the developing IPRS technology for catfish production and compare results to traditional pond culture of catfish.

There were two IPRS units in adjacent ponds. All units were stocked with approximately 15,000 hybrid catfish fingerlings averaging 33.7 g. Total feed fed, total weight gain, average daily weight gain, survival and feed conversion ratio (FCR) were monitored, analyzed and compared to industry standards.

All IPRS units were harvested in November 2015. Average final fish weights ranged from 420.4 g to 523.9 g. Average individual weight gains ranged from 384.1 g to 490.7 g. Average daily gain ranged from 1.31 g/d to 1.67 g/d. Survival ranged from 47-69%. FCR ranged from 1.59 to 2.14. The trial was not profitable at 0.85 IPRS cells/ha showing a loss of $1,542 - $5,701. However, when the IPRS unit density was scaled to the recommended 2.47 cells/ha there was a profit between $9,772 to $15,688 per pond.

Acknowledgements

I would like to thank my parents for their support throughout my scholastic career, without their support this would not have been possible. I would like to thank Dr. Jesse Chappell for his guidance throughout the thesis process as well as for his assistance and guidance in my career after graduation. I am also thankful for Dr. Terry Hanson for his assistance with keeping me on track during this process. I would like to thank Dr. Eric Peatman for his assistance during the review of my thesis. I am deeply indebted for the friendship and tutelage shown to me by Esau Arana during my time at Auburn. I am grateful for Mike Owens' help during this trial as well as for giving me the opportunity to gain insight into the real world operation of a commercial farm. The crew at Auburn's Agricultural Land Management also deserves a big thank you for their support of this as well as previous raceway studies. I would also like to thank the members who helped support this study: Stephen Holland, Lee Collins, Gary Walker, Ginger Stuckey, Tom Houston, Wilson Holland, Lisa Bott, Sunni Dahl, Max Westendorf and Ben Dosher.

Table of Contents

List of Terms and Abbreviations

Biomass – Refers to the total mass of fish or other organisms present in a pond.

Biological Oxygen Demand (BOD) – The amount of oxygen required by the organisms present in a body of water at a given time.

Dissolved Oxygen (DO) – The concentration of oxygen which is dissolved in the water.

In-Pond-Raceway System (IPRS) – The intensive fish culture system used in this study consisting of a water mover device attached to a fish confinement growth area.

Open Pond - Can refer to either a typical aquaculture pond culture area or to the portion of the pond in this study that was not occupied by the IPRS.

Standing Crop - The total biomass of fish present at a given period of time in an aquaculture production system.

Sock – An enclosed net shaped to hold harvested size fish until transport from the pond to the processing plant; it's mesh size allows sub-harvest sized fish to exit and remain in the pond until harvest size is achieved.

Water mover – The air diffuser along with hood enclosure that provides oxygen and flow to move water into and through the IPRS unit.

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Aquaculture Background

Aquaculture is a rapidly growing industry, which increased over 34% from 2006-2011 (FAO 2012). It is expected to soon surpass production from wild capture fisheries (Blumenthal 2013). The largest segment of U.S. aquaculture is catfish with food-size fish sales of 332 million dollars in 2014 (USDA 2015).

One large competitor of the United States catfish industry is imported Asian catfish. The majority of catfish fillets imported from Asia are from the genus Pangasius. Within the genus Pangasius the two most common species are *Pangasius hypophthalmus* and *Pangasius bocourti.* Both species are facultative air breathers. The native species culture in the United States do not have this trait. Additionally, many farms in Asia have the ability to exchange water at high volumes. The ability of *Pangasius* to grow in water with little to no dissolved oxygen along with the ability of farmers to exchange large volumes of water gives farmers the capacity to raise fish at high densities compared to production methods utilized by U.S. farmers. Production on farms in Vietnam, which exported 94,347 metric tons (MT) of catfish to the U.S. in 2011, often reaches 300 MT/ha/crop with two crops per year (Phan et al. 2009). In Alabama, Courtwright (2013) found an average production of 7,000 kg/ha/yr. The high production/ha in addition to reduced labor and operational costs lead to a much lower production cost for imported fillets, $0.89/kg (Phan et al. 2009) than domestically produced catfish, $2.40/kg (Courtwright 2013).

The U.S. catfish industry has been decreasing in size over the past decade with greater than 50 percent of farmers leaving the industry (Stewart 2013). That decrease continued in 2014 with a 1 percent decrease in sales and a 10 percent decrease in water surface acres from 2013 to 2014 (USDA 2015). Three of the most important factors influencing the profitability of an aquaculture system are fish survival, feed conversion ratio (FCR) and production. According to a survey by Blumenthal (2013), farmers estimate an average of 55% survival of catfish from the stocking of fingerlings to the harvest of market sized fish. Courtwright (2013) found the average FCR for farms in Alabama to be 2.3. As mentioned previously Courtwright found the average production in Alabama to be 7,000 kg/ha.

1.2 Partitioned Aquaculture System

As land and other resources have become limiting in aquaculture there has been a shift from passive culture to more intensified production. In 1995, Clemson researchers designed and built a system that was known as a partitioned aquaculture system (PAS). The principle of this system was maximizing algal uptake of nutrients as well as photosynthetic oxygen production. Their design of the PAS used paddlewheels to mix and circulate water throughout the pond. All fish within the PAS are confined to a culture area while the remainder of the pond is used for algal production. Inside the open portion of the pond researchers used either tilapia or mechanical means to remove algae. Using this system to optimize nutrient uptake and oxygen production, researchers were able to produce over 20,000 kg/ha/year (Brune et al. 2012).

1.3 Split-Pond Technology

Split-Pond systems are a modification of the PAS developed by Clemson. These systems, designed at Mississippi State University, rely on the similar principles as the original PAS. The split-pond system was built with the concept of confinement, to optimize feeding, disease treatment and harvest. PAS required a high degree of mechanization and intensification and the split-pond system was developed to realize some of the benefits seen in the PAS without as high a level of mechanization.

The design of the split-pond system, as the name implies, utilizes two ponds of unequal size bridged by canals. The smaller pond section is used to confine the fish while the larger pond is used to process fish wastes and maintain water quality. Fish are confined inside the smaller pond by screens which span the canals. Inside the canals are water movement devices, usually slow-rotating paddlewheels. During the day the algal pond produces a surplus of oxygen. However, at night the same pond has a very high oxygen demand. To prevent mortalities from low oxygen at night the water movement device is stopped and mechanical aeration is supplied to the smaller fish culture pond to maintain oxygen at adequate levels. This system has had production levels similar to the PAS ranging from 17,000-20,000 kg/ha (Brune et al. 2012).

1.4 Raceway History

A developing technology known as the In-Pond-Raceway-System (IPRS) has been in development at Auburn University for several years. The goal of this fish production system is to increase overall control and management of the production environment, including increasing production per unit area, reducing FCR and increasing survival during the grow out stage. The use of flowing water culture units for the production of catfish and other species has been of interest to researchers for many years. Sneed and Cozort (1959) first described a raceway system for catfish culture in 1959. J.R. Snow tested this design in 1962 for the culture of channel catfish fingerlings. He found a greatly improved survival of fry over the course of the study but a reduction in growth and FCR compared to open pond culture. Snow noted that the benefit of the raceways was not great enough to justify use in a commercial catfish fingering operation but that the improved survival showed enough promise to warrant continuing research Snow (1962).

Many early raceway designs utilized inefficient pumps to exchange water inside the raceway structure. A raceway design more similar to the modern design was described by Parker (1988) in a study examining striped bass fingerling growth. This system utilized a PVC airlift to cycle water through the 38 m x 1.3 m x 1.3 m floating raceway. Parker's design achieved a flow of 3,284± L/min. Parker described fingerling growth within the raceways as "excellent". Morrison et. al. (1995) tested a similar but smaller design for the production of catfish fry. The flow inside this design provided 12 exchanges/h, though at 1.87 m^3 this equated to a total flow of just 374 L/min/raceway. Additional aeration was provided through air stones to maintain dissolved oxygen. Morrison found overall survival of catfish fingerlings to be comparable to open pond culture but mentioned that the raceway system allowed for improvements in other areas such as improved feeding and disease treatment. A similar design was evaluated by Hawcroft (1994) at Auburn University. This design led to several studies at Auburn University on the production capabilities of raceways utilizing airlifts to cycle water. Hawcroft's design utilized 7.6-10 cm PVC airlifts to supply 190-225 L/minute of water exchange.

A design aspect with the early raceways was a water flow rate much lower than with more recent designs. This was likely due to the fact that during the time of their development most commercial catfish operations were utilizing lower stocking densities than modern operations and little to no additional aeration was required. When lower stocking densities are utilized, phytoplankton within the pond is able to produce enough oxygen to maintain DO levels sufficient for catfish with no mechanical oxygen addition. This meant that previous designs needed only to provide enough water to carry oxygen to maintain the BOD of the fish within the raceways. Today much higher stocking densities are used. These higher densities mean an increased BOD not only from the fish but also from the bacteria and plankton that are feeding on the waste of the fish. This increased BOD necessitates mechanical oxygen management.

The benefits of pond mixing have been noted before by Busch (1980) who illustrated a design for a slow rotating paddlewheel. Increased mixing allows for destratification of a pond in regard to oxygen. The bottom of aquaculture ponds tend to have low levels of oxygen due to the rapid oxygen use by bacteria which feed on both uneaten feed and fish waste. By mixing ponds this stratification is reduced and the waste can be processed more quickly. This reduces the nightly demand on oxygen and also can reduce the blue-green algae that lead to off-flavor fish flesh.

1.5 Modern Raceway Technology

Travis Brown (2011) tested a raceway design utilizing slow rotating paddle wheels to exchange water inside larger (7.71 m x 4.88 m x 1.22 m) commercial raceways. This methodology for water exchange produced greater water movement and circulation than previous designs. The water in this system was exchanged every 4.9 min. This is not significantly different than some previous designs, but what is different is the overall volume of water moved. In this case, due to the large raceway size, the entire volume of the pond was circulated every 12 h.

Brown (2011) showed the ability of in-pond raceways to produce catfish more economically than typical pond culture. This supports previous statements about the potential of in-pond raceways. Despite the large amount of water mixing in the Brown study depleted oxygen levels did become an issue during the latter part of the growout season. To improve oxygen levels inside the raceway air diffuser grids were placed at the pond bottom underneath the paddlewheels. This aeration had the two-fold benefit of oxygen addition as well as increased mixing. It was later discovered that by placing a hood over the top of the air diffuser; a horizontal element could be added to the vertical water movement caused by the diffuser grid. With this modification the entire mixing/raceway water exchange/aeration process could be handled efficiently without the need for a paddlewheel (Chappell, Auburn University).

One of the primary difficulties with more intensive systems such as raceways is the high initial investment. A follow up study to Brown's study by Fern (2014) investigated the use of floating in-pond raceways that could be constructed utilizing less expensive materials. Fern showed a difficulty in economically producing catfish at a commercial level. One problem mentioned was in the design of the floating in-pond raceways. The design utilized by Fern was made with the expectation of future use as research vessels. To this end, the raceways were designed smaller than that which would be used in a commercial setting. With these systems, as with many production systems, cost per unit of production increases with decreasing size. This may help explain the less than stellar economics presented in the Fern study. Since the study by Fern, larger commercial scale raceways have been constructed and installed at a farm in Perry County, West Alabama.

Another possible reason for the difficulties described by Fern were the species being cultured. Since the study by Fern, information from genetic studies utilizing the previously mentioned raceways has indicated that blue x channel hybrid catfish are likely more suitable for raceways than the pure channel catfish used by Fern. This could be due to several factors but one of the main contributors is likely the increased disease resistance of hybrid catfish. There has been a large increase in outbreaks of Aeromonas caused by virulent *Aeromonas hydrophila* in the Alabama catfish industry in recent years (Hemstreet 2010). Columnaris, caused by the bacteria *Flavobacterium columnare* is not new but is also a significant disease in the Southeast catfish industry. Hybrid catfish have been shown to have an increased resistance to columnaris (Arias et al. 2012). Preliminary results of ongoing studies have also shown them to be more resistant than channel catfish to aeromonas (Chappell, Auburn University)

Holland (2016) investigated several production techniques including the larger commercial scale floating raceways described previously. Holland's study failed to show increased profitability from the use of IPRS but again showed some of the benefits previously mentioned. However, greatly improved FCR (1.45-2.09) and survival (94-61%) were seen with this unit in a West Alabama commercial farm setting. One drawback of this study was that the fish did not reach harvest size in a single growing research period. This is likely due to the fact that the fish were not stocked until early July. This is much later than recommended and resulted in a greatly reduced growing period. Additionally, the commercial farm decided to harvest the fish early without understanding that feeding longer into fall is another benefit of the IPRS.

Many of the studies mentioned have shown the benefits of at least one of three primary production parameters (FCR, survival and growth rate). Many of these studies however have fallen short of showing the economic benefit that would be expected to accompany these improvements. This has been caused by several factors (early design flaws, species selection, late stocking etc.). The goal of this study was to evaluate the economic benefit of the current floating raceway system using the knowledge accumulated from previous studies.

1.6 Research Objectives

a) Determine if a 0.83 cell/ha IPRS setup is profitable;

b) Determine if a 2.47 cell/ha IRPS setup is profitable; and

c) Determine if bi-weekly screen cleaning affects water flow.

Chapter 2

Methods

2.1 Site Description

The site for this study was a commercial catfish operation in Dallas County, Alabama (West Alabama). This farm is owned by a large integrated seafood company that operates more than 1,800 ha of catfish production in Alabama and Mississippi. This company's current production system utilizes channel catfish in multiple-batch ponds. In multiple-batch production systems, multiple catfish age classes are present in a single pond at any given time. Partial seine harvests are conducted to remove market size fish while leaving undersized fish in the pond. This method allows for a more consistent feeding regime that maintains a higher and more consistent standing crop throughout the year than a single batch system and greatly increases the chance of having on-flavor fish for harvest at any time. The farm was willing to assist with this study in the hope of finding a new technology that would increase their farm's catfish survival, production and profitability.

Figure 2.1. The West Alabama catfish farm site for the In-Pond-Raceway System Trials, 2015.

A total of four 3.05 m x 12.2 m x 1.5 m IPRS's were constructed at Auburn University and installed at the farm in the Spring of 2014 (Holland, 2016). These four raceways were installed into two 2.43 ha ponds referred to by the farmer as Pond A7 and A15. These ponds were selected by the farm manager for their low production in previous years. Two factors contributed to the selection of ponds with a history of low production. First, the farmer wanted to minimize production losses in the case of a failed trial that yielded low production, and secondly, the farmer hoped to show an ability of the IPRSs in the future to increase production in lower quality ponds.

Figure 2.2: Close-up of the two commercial-scale ponds selected for the In-Pond-Raceway System study, 2015.

2.2 System Design

The floor frame of the IPRS structure was comprised of 7.62 cm angle aluminum with a 2.54 cm x 2.54 cm PVC coated steel wire mesh used to support the floor. The wall frame was constructed with galvanized steel unistrut. Inside this frame a high density polyethylene liner was attached to provide the confinement structure. This liner had a “U” shaped cross-section and consisted of two walls and a floor. At the inflow and outflow ends of the raceway a screen constructed of a 5.08 cm angle aluminum frame with 2.54 cm x 1.27 cm PVC coated steel wire mesh provided the confinement.

Floatation for the structure was provided by 12.12 m long x 25.4 cm diameter capped PVC pipe. These pipes were fixed to either side of the structure using a hanging bracket fixing the pipe to the vertical unistrut of the wall frame. The floatation was fixed at a height that allowed for approximately 0.30 m of freeboard to prevent escapement of jumping or aggressively feeding fish.

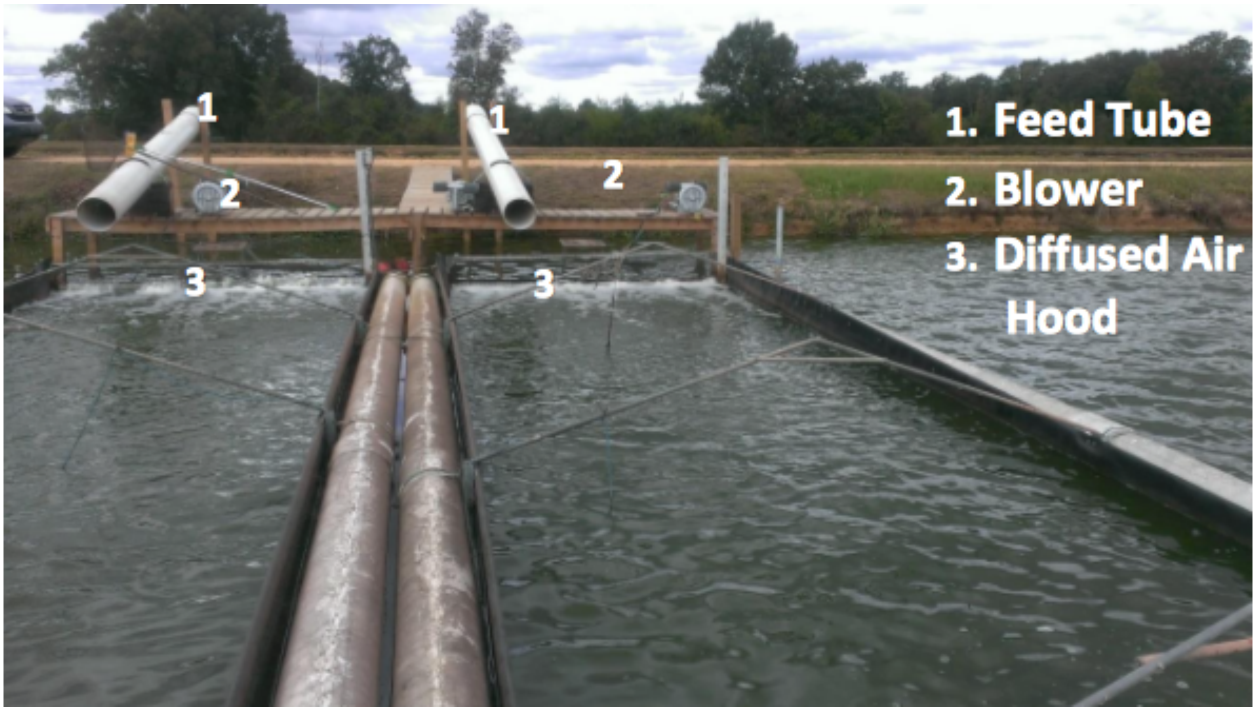

Figure 2.3: The In-Pond-Raceway System set up in the study pond (Holland 2016).

The water aeration/circulation apparatus, which will be referred to as a water mover through the rest of this paper, was built using aero tubing purchased from Swann Industries, Marion, OH. This aero tubing is made to produce a small air bubble that would allow effective oxygen transfer as the bubble rises to the water surface without being so small as to require excessive maintenance. This tubing was attached to a 10.16 cm PVC frame to create a grid of aero-tubing. The diffuser hood, which was used to hold the diffuser grid and divert the vertical water flow into a horizontal flow, was built using angle and sheet aluminum. The water mover was attached to the raceway so that the top of the water mover was at water level and the grid was approximately .838 m below the surface, allowing for an air bubble rise of .838 m and create flow through the IPRS unit.

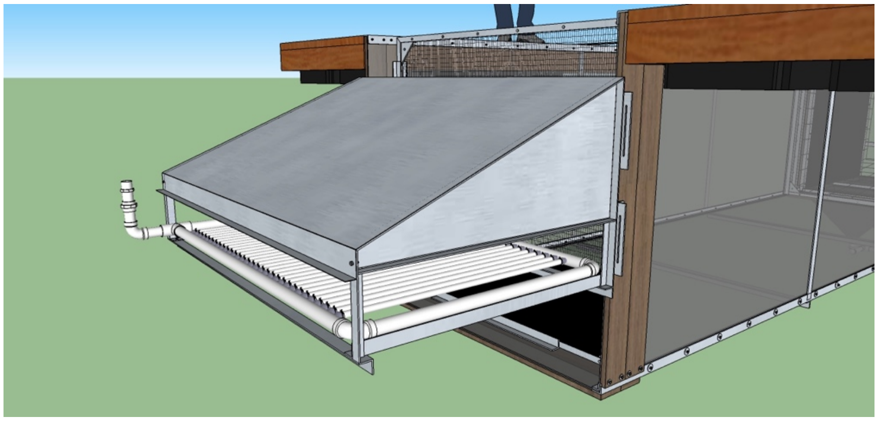

Figure 2.4: The water mover apparatus attached to the front end of the In-Pond Raceway System.

To assist with feeding and maintenance a dock was built using pressure treated lumber to allow access to the front/inflow of the raceways. The PVC flotation was used as a dock for access to the rear (outflow end) of the raceways but it is recommended that future designs include an additional dock to the rear of the IPRS unit for easier access. A 30.48 cm PVC pipe was placed from the bank of the levee to the front of the raceway to assist with stocking and feeding of fish.

A water quality monitoring system was installed by Pentair (Apopka, FL). Two sensors were place inside each raceway to monitor DO, pH, and temperature, one approximately 6.0 m downstream of the inflow screen and one 9.1 m downstream. There was also a sensor placed on the outside of the raceway near the IPRS water inflow in order to investigate the differences in water quality inside and outside the raceways.

On commercial catfish farms it is typical to have employees regularly check dissolved oxygen (DO) of ponds throughout the day and night. These employees took semi-regular readings from the open pond as well as inside the raceways using a handheld dissolved oxygen meter as part of their daily route. During the course of the study, as water temperatures increased, it was determined that excessive bio-fouling was causing inaccurate readings from the automatic water quality monitoring meters. Increased cleanings did not improve accuracy significantly and it was deemed that the readings would be too unreliable to be of any use.

Due to investment constraints only four raceways were constructed and installed into two 2.43 ha ponds, resulting in a raceway density of 0.85 IPRS cells/ha, much lower than the recommended 2.47 IPRS cells/ha. In the study by Holland (2016) raceway cells were stocked while the remainder of the pond was left vacant. As expected, the low raceway density resulted in a per hectare production that was much lower than would be seen with an open pond. For the purpose of Holland's study, the data was extrapolated to 2.47 IPRS cells/ha to determine the hypothetical profitability of the IPRS system in a commercial pond setting. However, the farm operation's management staff were unwilling to allow the ponds to remain unstocked for this study due to the reduction in overall production.

2.3 Stocking

Stocking was conducted on January 22, 2015. All raceway cells were stocked with hybrid catfish (female *Ictalurus punctatus x male Ictalurus furcatus)*. Subsamples were taken during stocking to determine the average catfish weight and number of catfish stocked. The goal was to stock 15,000 catfish per cell. The actual number stocked varied from 14,820 to 16,797 (327-371/m^3) with the large variation possibly being due to inaccuracy in the hatchery samples which used samples from only two of the four delivery tanks to estimate stocking numbers and weights. These numbers were used to load the four tanks that would be stocked into the four IPRS raceway cells. On-site sampling however indicated a significant difference in average size of fish in each tank leading to a large variation in fish numbers despite a relatively consistent total stocking weight. The average size at stocking for each raceway ranged from 32.5 g – 34.9 g with an average length from 16.4 cm – 16.6 cm.

The majority of the fish in the previous years' study by Holland (2016) did not reach harvest size (at least .452 kg). As a result, the farm manager decided to release the IPRS fish into the open pond. All fish from Holland's study were harvested, weighed and released into the open portion (non-IPRS) of Pond A15 for final growout. Farm management also decided that the open portion of Pond A7 and A15 would be stocked with fingerling channel catfish. A total of 22,670 hybrid catfish and 18,369 channel catfish were stocked into A15, the average size of hybrids was 396.6 g. The average size of channels was 235.3 g.

The farm also stocked an additional batch of channel catfish on November 7, 2014 into both Pond A7 and Pond A15 after the harvest of Holland's study. A total of 36,950 fish with an average weight of 21.18 g were stocked into Pond A7. A total of 36,864 fish with an average weight of 23.36 g were stocked into Pond A15. The total combined stocking for each open pond portion was 36,950 head in Pond A7 and 77,903 head in Pond A15.

2.4 Operation

Feeding was managed and recorded by the farm manager. The standard method for feed delivery on most U.S. catfish farms is with a large truck equipped with a feed hopper and blower. The truck is driven the length of a pond levee while the blower dispenses feed evenly to the fish. For the IPRS setup a flexible tube was utilized to bridge the distance from the output of the truck hopper to the IPRS feed delivery pipe. The farmer would insert the flexible pipe into the PVC delivery pipe and turn on the blower until the daily feed ration had been delivered. Feeding varied from 1-2x per day and the daily ration was left to the farmer's discretion.

On Mondays and Fridays of each week a researcher from Auburn University would travel to the research farm site to clean the confinement screens and sensors in the water quality monitors. The water quality monitoring system also required occasional calibration. Researchers would also remove and investigate catfish mortalities. A treatment bath of either formalin or potassium permanganate would be applied if the mortalities reached greater than 10 dead fish / day or if mortalities were lower than 10 but exhibited signs of a developing disease.

To assist with chemical treatments a curtain was constructed using a 3.66 m x 1.8 m poly tarp. A 2.75 m x 1.25 cm steel bar was added to the bottom of the curtain as a weight. A 3.35 m x 3.81 cm PVC pipe was attached to the top to act as a hangar. During treatments the curtain was deployed on the downstream end of the raceway inside the confinement screen. Aeration was also reduced to prevent any backflow that would result in water exchange. During the treatment, researchers were careful to monitor oxygen content within the raceways and abort the treatment if dissolved oxygen went below 2 mg/L. Treatments were staggered between formalin and potassium permanganate. Formalin was applied at a rate of 125 ppm. Potassium permanganate was applied at 6-8 ppm. The goal was to treat for 25 minutes with either treatment if oxygen remained above 2 mg/l (ppm).

On days when researchers were not present, farm employees would manage the removal and disposal of mortalities. If mortalities were exceptionally high, farm personnel would treat in the manner previously described. If mortalities were present but not above normal, the number removed was reported to the researchers but no treatment was given.

After attempting several water flow trials, it was determined the water flow was too slow to allow for accurate readings with the available electronic flow-meters. Thus, a modified float method was used to measure water flow through the raceways. The aim of this measurement was to determine the effect of screen cleaning on the circulation of water through the IPRS units. Due to the orientation of the water mover and the flow dynamics it produced, the velocity at the inflow was much greater at the top of the water column than closer to the bottom where the water flow was much slower. If the standard float method, where a float is placed on the water and timed over a known distance, were used an artificially high flow would be measured.

To gain an understanding of the flow throughout the raceway water column, both in terms of across depths and longitudinally across the raceway, we constructed vertical floats from 1.2 m x 2.54 cm PVC. These floats were weighted with sand to achieve just greater than neutral buoyancy. Because the floats were heavily weighted at the bottom and buoyant on top they maintained a vertical orientation regardless of differences in flow rates in the depth profile. This allowed the researchers to measure the total flow throughout the depth of the raceway. To measure the water flow rate researchers would release the floats and measure the time taken for the float to drift the length of the raceway. To account for differences in flow from the outer edges to the center of the raceway 4 measurements were taken for each raceway. Two measurements with the float being dropped along the outer wall and two with the floats beginning at approximately 1 meter from each wall. To measure for water flow differences caused by screen cleaning, this regimen was conducted both before and after screen cleaning.

On November 16, 2015 a sample of approximately 45.4 kg was randomly selected from each raceway and the average length and weight of individuals was taken. Harvest was conducted the following day. The harvest was transferred into a seining sock built to allow under sized fish to exit while retaining fish large enough to be accepted by the processing plant. The fish were left to grade overnight and those remaining in the morning were shipped to the processing plant. The total weight harvested, weight processed and yield were recorded.

The open ponds were harvested according to the farm manager's recommendation based on the presence of food size fish and the processors needs. Pond A15 was harvested twice during the IPRS production trial, once on June 10, 2015 and again on October 30, 2015. Pond A7 was harvest once during the trial on October 28, 2015.

2.5 Analysis

After harvest the average daily weight gain, total weight gain, production/ha, FCR and fillet yield were calculated for each pair of raceways. The total weight gained and production/ha of the entire pond including open pond harvests were also calculated. The survival and FCR for the entire pond system was not available due to the fact that the farm utilizes partial harvesting which means that an unknown portion of fish were left in the ponds after partial harvestings to continue growout to harvest size. Under these circumstances it is impossible to know what portion of fish is left in the pond and what portion of fish became a mortality.

It is impossible to compare production in a given year for a raceway system, which relies on complete harvests, to an open pond that uses partial harvest. This is because an open pond, especially one which has recently been completely harvested as Pond A7 and Pond A15 had been, will not have consistent annual production numbers. For comparison the production numbers from the raceways will be extrapolated to reflect a 2.47 IPRS cells/ha density and compared to previous Alabama industry production standards established by Courtwright (2013).

Initially, enterprise budgets were constructed using the true 0.85 raceway/ha data. Additionally, enterprise budgets were constructed to determine the cost of production of a kg of fish with IPRS systems using the extrapolated 2.47 IPRS/ha data. Also, it was found that feeding in the IPRS was reduced during the final stages of production (August through November), so an enterprise budget was constructed to reflect projected data for what would have been found had feeding been conducted at the recommended levels to a normal seasonal fish crop completion date.

For this estimate of production, a 1.5% bodyweight/day feeding from the 12th of August on was projected; estimates were made assuming all mortalities occurring from August 6th through October 4th occurred during the disease outbreak from August 6th through 12th. With this assumption a biomass for each raceway was estimated on August 12th. Using this estimate the rest of the weekly feeding averages were projected assuming 1.5% of biomass in the IPRS would be fed per day from August 12th through October 14th. Holland's IPRS trial (2016) showed feeding was greatly reduced after October 16th, so for this reason the projection used a 0.75% bodyweight/day feeding rate from the week of October 14th until the conclusion of the study (November 17, 2015).

Biomass estimates were made using the equation:

$$\text{Original biomass} + \text{feeding}*\text{projected FCR} = \text{current biomass} \quad (1)$$

FCR typically increases (i.e., less efficient) as fish size increases and because this projection assumes greater fish growth than was seen, the projected FCR was increased (less efficient) by 0.2 from what was recorded during the IPRS trial. These adjusted scenarios were analyzed for profitability and compared to that found in standard West Alabama pond catfish aquaculture (Courtwright, 2013). In order to make a direct comparison to 2012 industry standards, budgets were also produced using average fish selling and input prices used by Courtwright.

Chapter 3

Results

3.1 Water Quality

In the first quarter of production Pond A7 and Pond A15 had alkalinity levels (15 and 40 mg/L respectively) that were far below the levels recommended by Courtwright (2013). Hardness levels during this period were also much lower that recommended (34 and 34 mg/L respectively). After the addition of agricultural lime in April the alkalinity of Pond A7 ranged from 80 - 110 mg/L. This is much closer to the 115 mg/L recommended by Courtwright. The alkalinity of Pond A15 after the addition of agricultural lime ranged from 130 - 135 mg/L. Hardness also increased after this amendment, ranging from 80-110 mg/L and 90 mg/L for Pond A7 and Pond A15, respectively.

Nitrite levels ranged from (0 - 0.6 mg/l). Nitrite toxicity is strongly affected by chloride levels, with a minimum chloride:nitrite ratio of 10:1 being recommended (Durborow et al. 1997). Pond A7 and Pond A15 maintained chloride levels above 125 mg/L. At these levels nitrite toxicity would not be expected to have any negative impacts.

Total ammonia nitrogen (TAN) levels varied greatly between the two ponds and across the culture period. Both ponds reached levels that could be considered detrimental to fish health. The key factor contributing to the toxicity of ammonia is the un-ionized portion of the total ammonia nitrogen. The factors that determine the portion of ammonia that is un-ionized are temperature and pH. A reading of 6 mg/L TAN was taken from Pond A7 prior to harvest in November, with normal temperatures for this period and typical pH this would not have been acutely toxic but could have been detrimental if fish were exposed over an extended time frame. A sample taken from Pond A7 in August had a reading of 2.1. This along with the ambient pH and temperature would lead to levels of un-ionized ammonia that border on concentrations that could lead to chronic toxicity. Pond A15 had similar readings for TAN with the exception that TAN in Pond A15 reached its peak of 6.4 mg/L in August.

The pH within aquaculture ponds is known to fluctuate to a large degree during a given day due to the photosynthetic process of algae. For this reason, it is difficult to know the exact amount of toxic ammonia present throughout a given day. However, calculating uni-ionized ammonia using 6.4 mg/L TAN along with summer temperatures and the usual pH range for this pond lead researchers to believe uni-ionized ammonia reached levels well beyond chronic and bordering on acutely toxic. The timing of this measurement correlates with a large disease outbreak and high mortalities within Pond A7.

The disease outbreak that caused mortalities inside the raceway also led to mortalities of fish in the open pond. Though all mortalities were removed from raceway cells, mortalities inside the open pond were left to decompose. It is unknown if the high ammonia at this time caused a reduced immune capacity in the fish that lead to disease. Another possibility is that the large mass of organic waste caused by the fish kill resulted in the raised ammonia levels (Hargreaves and Tucker 2004).

3.2 Water Flow

The water flow data showed that cleaning of IPRS screens can make a large difference in water flow rates. The average increase in water flow after cleaning varied greatly (12-41%) but was significant for all raceways. The average water flow rate after cleaning was determined to be 0.07 m/s which is similar to that found by Holland (2016). The average volumetric water flow was found to be 941,936 l/hr or 261 l/sec. This equates to one complete exchange of the cell water every 2.9 minutes. This is faster than the 4.9 minutes found by Brown (2011) in concrete raceways using paddlewheels to circulate water. The water flow findings are provided in Table 3.1.

Table 3.1: Raceway flow averages before and after screen cleaning.

	Pond A7-RW		Pond A15-RW	
Raceway	1	2	1	2
Pre-Cleaning Velocity (m/sec)	0.04	0.058	0.068	0.067
Post-Cleaning Velocity (m/sec)	0.058	0.073	0.07	0.082
Increase (%)	41	24	12	22
Post-Cleaning Volume (liters/hr)	786,987	958,246	941,935	1,080,576

3.3 Mortalities

The majority (86%) of mortalities in the raceway systems came during two disease outbreaks, the first caused by *Flavobacterium columnare* (51%) and the second by virulent *Aeromonas hydrophila* (35%). The first of these events began in late April and ran into early May. This event caused similar mortalities in both Pond A7 and Pond A15. Both were treated biweekly with a rotation of formalin and potassium permanganate. Columnaris caused by *Flavobacterium columnare* is a common disease in this region. A study by the USDA (2010) found that 25.7% of growout ponds in this region experienced at least minimal losses due to columnaris. The second disease outbreak was caused by virulent *Aeromonas hydrophila*. *Aeromonas hydrophila* has been present throughout the history of catfish culture in the United States.

Beginning in 2009, the appearance of a new, highly virulent strain of *A. hydrophila* began in West Alabama and has had a severe impact on catfish farms in Alabama (Hossain et al. 2014). This disease also caused a less severe (5%) mortality event in late June-early July. It should be noted that there was mortality in the open pond of both Pond A7 and Pond A15 in September due to *Aeromonas*, however no mortalities were seen in the raceways at this time. There is one approved antibiotic feed, Terramycin, that can be used to treat aeromonas outbreaks (Hemstreet 2016). The particular farm this trial was conducted on uses a different treatment strategy. It is the manager's opinion that by reducing or ceasing feed intake the disease can be reduced. It is his belief that the benefit of antibiotic feed over reduced feeding is not enough to justify the increased price of antibiotic feed.

3.4 Production

The total fish mass harvested from Pond A7 in November of 2015 was 18,314 kg with 9,793 kg of this total coming from the two IPRS raceway cells and 8,521 kg coming from the open pond. The weight of fish stocked into Pond A7 was 1,794 kg; and subtracting this from the total fish mass results in the total production from Pond A7 being 16,520 kg or 6,798 kg/ha.

The total fish mass harvested from Pond A15 was 43,122 kg with 8,013 kg coming from the two IPRS raceway cells and 35,109 kg coming from the open pond. The weight of fish stocked into Pond A15 was 15,261 kg; and the total production from Pond A15 after accounting for stocking weight was 27,861 kg or 11,465 kg/ha.

The growing period for the raceway fish was 294 days. The growing period for the fish stocked into Pond A15 from the previous raceway study was 215 days to the first harvest and 352 days to the second harvest. The growing period for the fish stocked from the hatchery into Pond A15 was 220 days to the first harvest and 357 days to the second harvest.

Table 3.2: Harvest and Growth data from In-Pond-Raceway Cells

Pond	A7 Cell 1	A7 Cell 2	A15 Cell 3	A15 Cell 4
Harvest Date	11/17/15	11/17/15	11/17/15	11/17/15
Duration (days)	294	294	294	294
Harvest Weight (kg)	4,735	5,075	4,456	3,556
Processed Weight (kg)	5,193		4,982	
Harvest Numbers	10,265	9,645	10,599	7,327
Harvest Size (kg/each)	0.461	0.524	0.420	0.485

Table 3.3: Production Parameters for In-Pond-Raceway Cells

Pond	A7 Cell 1	A7 Cell 2	A15 Cell 3	A15 Cell 4
Weight Gained (kg)	4,232	4,549	3,912	3,016
Gain per Day (g/fish/day)	1.57	1.78	1.43	1.65
Feed Fed (kg)	6,899	7,212	6,744	6,318
FCR (feed fed/ [End wt. – beg. Wt.])	1.63	1.59	1.72	2.14
Survival %	69.2	64.2	63.1	47.1

Table 3.4: Extrapolated In-Pond-Raceway-System Production (2.47 cell/ha)

Pond	A7	A15
Stocked (#)	89,496	97,056
Harvested (kg)	29,379	24,038
Produced (kg)	26,366	20,785
Production per area (kg/ha)	10,895	8,589

The extrapolated production for the two pond trials compares favorably with the average production found in Alabama commercial production ponds by Courtwright (2013). Courtwright found an average production of 7,526 kg/ha in 2011 and 6,841 kg/ha in 2012. It is significantly lower than the production found in split ponds (17,000-22,000 kg/ha; Brune et al. 2012). Intensively aerated ponds have also been shown to have a production similar, albeit less consistently, to that of split ponds. Brown (2011) also showed the ability of in-pond-raceways to reach similar production to that shown for split and intensively aerated ponds.

The length and weight of individual fish was taken from each raceway and used to create an equation to predict weight given a specified length. The results were similar to those found for channel catfish in the study by Holland (2016).

$$M = 18.196e^{0.0869L} \tag{2}$$

$$M = 15.082e^{0.0924L} \tag{3}$$

where M is mass in grams and L is length in centimeters.

Of the 17,806 kg of harvested catfish from IPRS raceways 57.2% were large enough to be accepted by the processor. The majority of those fish not processed were close to harvest size, with only 2.5% of fish <225 g and 54.6% between 225-450 g. Twenty-eight percent were from 450- 675 g and 15.1% were >675 g. Figure 3.1 shows the size distribution chart of fish harvested from the raceways.

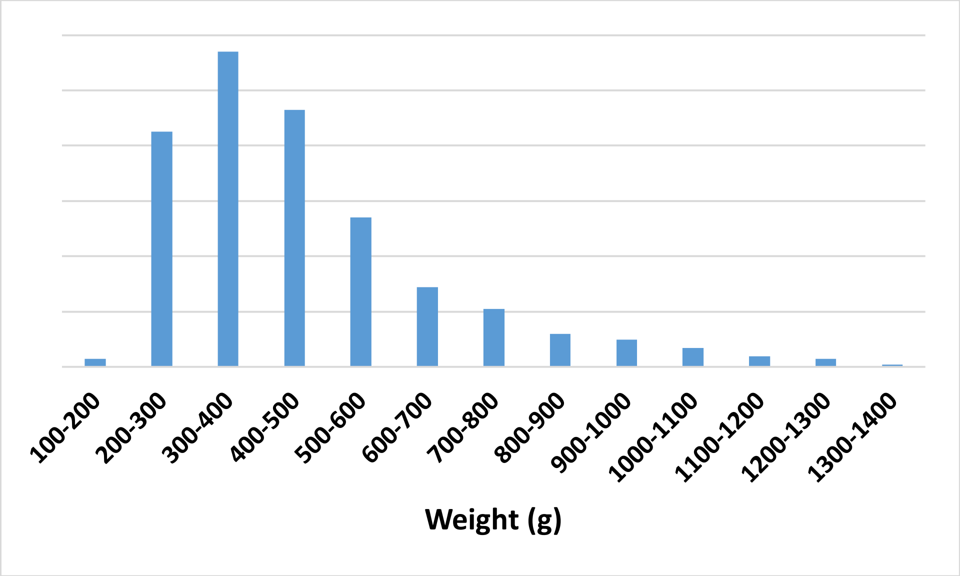

Figure 3.1. Size distribution of harvested catfish sampled from IPRS raceways.

Table 3.5. Open Pond and Overall Production Data

Pond	A7	A15	A15
Harvest Date	10/28/15	6/10/15	10/30/15
Duration (days)	355	210-215	352-357
Harvest Weight (kg)	8,522	19,796	15,314
Production (kg Harvested – Stocked)	6,797	19,895	
Total Production (including production from IPRS)	15,578	26,823	
Production/ha (kg/ha)	6,410	11,038	

The IPRS raceway production for the two study ponds was similar (8,781 kg - 6,928 kg) with differences being attributed to an aggressive outbreak of *Aeromonas hydrophila* in Pond A15 in July 2015. The overall pond production was vastly different for the two ponds (15,578 kg - 26,823 kg). Several factors contributed to this difference. Pond A15 was stocked with large fish from the previous years' study. Larger fish have a greater daily growth rate than smaller fish meaning the total daily growth of a pond with larger fish will be greater than that of a pond stocked with an equal number of smaller fish. Another factor contributing to the greater production was the number of fish stocked into the open ponds. The open pond of Pond A15 was stocked with 77,903 hybrids and channel catfish. The open pond of Pond A7 was stocked with 36,950 channel catfish, less than half the number present in Pond A15. The last factor contributing to the greater production in Pond A15 was the presence of hybrid catfish. Hybrid catfish have been shown to have a greater growth rate than pure channel catfish (Yant et al., 1975; Chappell, 1979).

3.5 Feeding

The feeding of the raceways is shown in Figure 3.2. Daily feed average peaked at approximately 90 kg/day in late July and fell sharply thereafter. The average weekly feeding was never greater than 70 kg/day in the month of August and was never greater than 45 kg/day in September. The feed regime resembled an exponential curve until a heavy *Aeromonas hydrophila* outbreak in Pond A15 at the end of July. The feeding was originally reduced per farm management protocol for an aeromonas outbreak. This same regime was followed with success during the smaller outbreak in late June. However, the feeding after the original disease event rebounded to greater than it had been before the event, continuing on the trend of exponential growth.

The feeding after the second event did not rebound to fit the exponential curve. Instead, it fell gradually until harvest. The manager in charge of feeding believed excessive feed to be the cause of the *Aeromonas* outbreak. To prevent further disease loss at the end of the production cycle when biomass is highest, the manager reduced feeding below pre-disease levels. Although only the cells in Pond A15 were affected by *Aeromonas*, the manager reduced feed in Pond A7 along with Pond A15. The total feed fed was similar for each raceway ranging from (7,212 - 6,318 kg) with the lowest likely being due to reduced feeding during disease outbreaks.

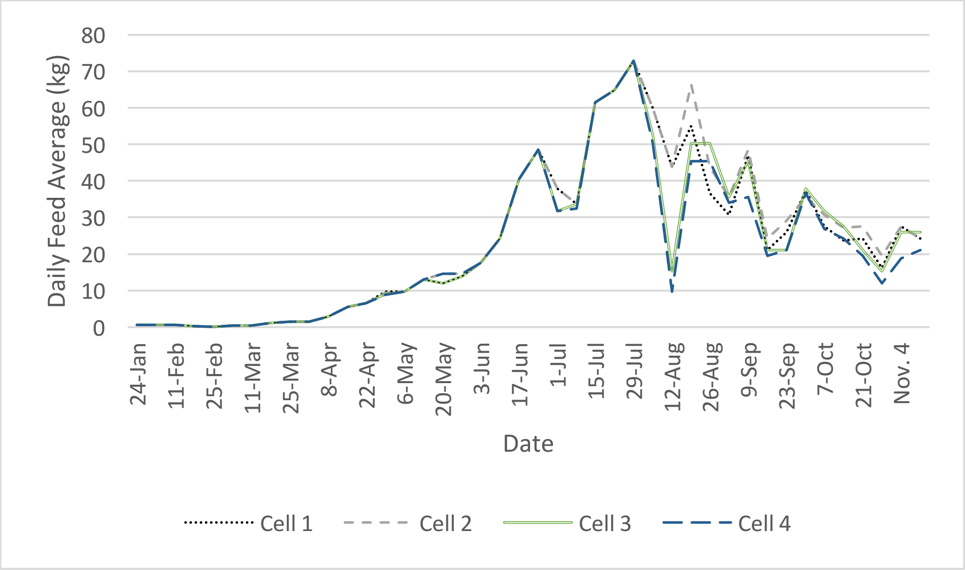

Figure 3.2. Average Daily Feeding by raceway cell throughout the culture period.

3.6 Economics

The budget analysis of the IPRS setup showed a loss of $1,542 for Pond A7 and a loss of $5,701 for Pond A15 at the average 2015 price for feed and fish, Table 3.6. These losses are likely due to the fact that the number of raceways was too low for what the pond could/should have contained. The number of experimental IPRS raceways for fish production was much lower than what would be the recommended commercial setup scale of 2.47 IPRS cells/ha. With this reduced setup the investment and fixed costs of land and equipment were artificially high per unit of production. The sensitivity analysis, Table 3.7, further illustrates this. There was no scenario where 0.85 IPRS cells/ha were profitable.

Table 3.6: Enterprise budget for 0.85 IPRS/ha producing hybrid catfish at a commercial farm in West Alabama, 2015.

Budget Parameter										
Pond			A7				A15			
Harvest Mass (kg)			9,810				8,012			
Growth Period (Months)			10				10			
	$/Unit	Units	#	$	$/ha	$/kg	#	$	$/ha	$/kg
Recipes	2.49	kg	9,810	24,427	10,060	2.49	8,012	19,950	8,216	2.49
Variable Costs										
Feed	0.44	kg	15,365	6,761	2,784	0.69	14,224	6,259	2,578	0.78
Labor and Management	13	$/hr	168	2,226	917	0.23	168	2,226	917	0.28
Fingerlings	0.16	$/fish	29,832	4,783	1,970	0.49	32,352	5,187	2,136	0.65
Harvest and Transport	0.11	$/kg	9,810	1,079	444	0.11	8,012	881	363	0.11
Energy	0.0756	$/kWh	33,756	2,552	1,051	0.26	33,756	2,552	1,051	0.32
Chemicals										
Formalin	2.12	$/L	117.4	249	103	0.03	117.4	249	103	0.03
Potassium permanganate	5.1	$/kg	24.9	127	52	0.01	24.9	127	52	0.02
Interest on Operating Capital	10.0%	percent	13,332	1,333	549	0.14	13,111	1,311	540	0.16
Total Variable Costs				**19,110**	**7,870**	**1.95**		**18,792**	**7,739**	**2.35**
Income Above Variable Costs				5,317	2,190	0.54		1,158	477	0.14
Total Fixed Cost (adjusted for 294 culture days)				6,859	2,825	0.70		6,859	2,825	0.86
Total Cost				25,968	10,695	2.65		25,650	10,564	2.65
Net Return Above Expenses				**(1,542)**	**(635)**	**(0.16)**		**(5,701)**	**(4,351)**	**(1.09)**

	A7	A15
Breakeven Price to Cover, Variable	1.95	2.35
Breakeven Price to Cover, Total	2.65	3.20

Table 3.7: Sensitivity analysis - estimated net returns above total cost in ponds with 0.85 cells/ha at varying fish selling price and feed costs.

	Price of Fish ($/kg)										
Feed Prices ($/Kg)	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6
0.36	-10,280	-9,388	-8,497	-7,606	-6,715	-5,824	-4,933	-4,042	-3,151	-2,260	-1,369
0.38	-10,598	-9,707	-8,815	-7,924	-7,033	-6,142	-5,251	-4,360	-3,469	-2,578	-1,687
0.40	-10,916	-10,025	-9,134	-8,242	-7,351	-6,460	-5,569	-4,678	-3,787	-2,896	-2,005
0.42	-11,234	-10,343	-9,452	-8,560	-7,669	-6,778	-5,887	-4,996	-4,105	-3,214	-2,323
0.44	-11,552	-10,661	-9,770	-8,879	-7,987	-7,096	-6,205	-5,314	-4,423	-3,532	-2,641
0.46	-11,870	-10,979	-10,088	-9,197	-8,306	-7,414	-6,523	-5,632	-4,741	-3,850	-2,959
0.48	-12,188	-11,297	-10,406	-9,515	-8,624	-7,733	-6,841	-5,950	-5,059	-4,168	-3,277
0.50	-12,506	-11,615	-10,724	-9,833	-8,942	-8,051	-7,160	-6,268	-5,377	-4,486	-3,595
0.52	-12,824	-11,933	-11,042	-10,151	-9,260	-8,369	-7,478	-6,586	-5,695	-4,804	-3,913
0.54	-13,142	-12,251	-11,360	-10,469	-9,578	-8,687	-7,796	-6,905	-6,013	-5,122	-4,231
0.56	-13,460	-12,569	-11,678	-10,787	-9,896	-9,005	-8,114	-7,223	-6,332	-5,440	-4,549

When the results were scaled to represent a pond with 2.47 IPRS/ha the result was a profit of $15,688 for Pond A7 and $9,772 for Pond A15, Table 3.8. When the number of raceways per pond were increased the relative cost of pond construction and other fixed costs was reduced, an economy of scale.

Table 3.8. Enterprise budget for 2.47 IPRS/ha producing hybrid catfish at a commercial farm in West Alabama, 2015.

Budget Parameter										
Pond			A7				A15			
Harvest Mass (kg)			29,430				24,036			
Growth Period (Months)			10				10			
	$/Unit	Unit	#	$	$/ha	$/kg	#	$	$/ha	$/kg
Receipts	2.49	kg	29,430	73,281	30,180	2.49	24,036	59,850	24,649	2.49
Variable Costs										
Feed	0.44	kg	46,095	20,282	8,353	0.69	42,672	18,776	7,733	0.78
Labor and Management	13	$/hr	420	5,565	2,292	0.19	420	5,565	2,292	0.23
Fingerlings	0.16	$/fish	29,832	4,783	1,970	0.16	32,352	5,187	2,136	0.22
Harvest and Transport	0.11	$/kg	29,430	3,237	1,333	0.11	24,036	2,644	1,089	0.11
Energy	0.0756	$/kWh	101,268	7,656	3,153	0.26	101,268	7,656	3,153	0.32
Chemicals										
Formalin	2.12	$/L	352.2	747	308	0.03	117.4	249	103	0.01
Potassium permanganate	5.1	$/kg	74.7	381	157	0.01	24.9	127	52	0.01
Interest on Operating Capital	10.0	percent	31,988	3,199	1,317	0.11	30,153	3,015	1,242	0.13
Total Variable Costs				**45,849**	**18,883**	**1.56**		**43,219**	**17,799**	**1.80**
Income Above Variable Costs				27,431	11,297	1		16,631	6,849	0.69
Total Fixed Cost (adjusted for 294 culture days)				11,743	4,836	0.40		6,859	2,825	0.29
Total Cost				57,593	23,719	1.96		50,077	20,624	2.65
Net Return Above Expenses				**15,688**	**6,461**	**0.53**		**9,772**	**4,025**	**0.41**

	A7	A15
Breakeven Price to Cover, Variable	1.56	1.80
Breakeven Price to Cover, Total	1.96	2.08

Table 3.9:: Sensitivity analysis - estimated net returns above total cost in ponds with 2.47 cells/ha at varying fish selling price and feed costs.

	Price of Fish ($/kg)										
Feed Prices ($/Kg)	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6
0.36	-7,245	-4,572	-1,899	775	3,448	6,121	8,795	11,468	14,141	16,815	19,488
0.38	-8,199	-5,526	-2,853	-179	2,494	5,167	7,840	10,514	13,187	15,860	18,534
0.40	-9,154	-6,480	-3,807	-1,134	1,540	4,213	6,886	9,559	12,233	14,906	17,579
0.42	-10,108	-7,435	-4,761	-2,088	585	3,259	5,932	8,605	11,279	13,952	16,625
0.44	-11,062	-8,389	-5,716	-3,042	-369	2,304	4,978	7,651	10,324	12,998	15,671
0.46	-12,016	-9,343	-6,670	-3,996	-1,323	1,350	4,023	6,697	9,370	12,043	14,717
0.48	-12,971	-10,297	-7,624	-4,951	-2,277	396	3,069	5,742	8,416	11,089	13,762
0.50	-13,925	-11,252	-8,578	-5,905	-3,232	-558	2,115	4,788	7,462	10,135	12,808
0.52	-14,879	-12,206	-9,533	-6,859	-4,186	-1,513	1,161	3,834	6,507	9,181	11,854
0.54	-15,833	-13,160	-10,487	-7,813	-5,140	-2,467	206	2,880	5,553	8,226	10,900
0.56	-16,788	-14,114	-11,441	-8,768	-6,094	-3,421	-748	1,925	4,599	7,272	9,945

When the results were projected to 2.47 cells/ha and production within cells that reflects a 1.5% per day feeding rate as described in the methods section, the profitability of the system being profitable is much greater, Table 3.10. With this scenario there were few feed/fish price combinations resulting in a negative profit, Table 3.11.

Table 3.10: Projected enterprise budget for 2.47 IPRS/ha producing hybrid catfish at a commercial farm in West Alabama, 2015.

Budget Parameter										
Pond			A7				A15			
Harvest Mass (kg)			38,275.94				28,631.17			
Growth Period (Months)			10				10			
	$/Unit	Unit	Quantity	$	$/ha	$/kg	Quantity	$	$/ha	$/kg
Receipts	2.49	kg	38,276	95,307	39,252	2.49	28,631	71,292	29,361	2.49
Variable Costs										
Feed	0.44	kg	56,748	24,969	10,283	0.65	47,666	20,973	8,638	0.73
Labor and Management	13	$/hr	420	5,565	2,292	0.15	420	5,565	2,292	0.19
Fingerlings	0.16	$/fish	29,832	4,783	1,970	0.12	32,352	5,187	2,136	0.18
Harvest and Transport	0.11	$/kg	38,276	4,210	1,734	0.11	28,631	3,149	1,297	0.11
Energy	0.0756	$/kWh	101,268	7,656	3,153	0.20	101,268	7,656	3,153	0.27
Chemicals										
Formalin	2.12	$/L	352.2	747	308	0.02	117.4	249	103	0.01
Potassium permanganate	5.1	$/kg	74.7	381	157	0.01	24.9	127	52	0.00
Interest on Operating Capital	10.0%	percent	36,233	3,623	1,492	0.09	32,180	3,218	1,325	0.11
Total Variable Costs				**51,934**	**21,389**	**1.36**		**46,124**	**18,996**	**1.61**
Income Above Variable Costs				43,373	17,863	1		25,167	10,365	0.88
Total Fixed Cost (adjusted for 294 culture days)				11,743	4,836	0.31		6,859	2,825	0.24
Total Cost				63,677	26,225	1.66		52,983	21,821	2.65
Net Return Above Expenses				**31,630**	**13,026**	**0.83**		**18,309**	**7,540**	**0.64**

	A7	A15
Breakeven Price to Cover, Variable	1.36	1.61
Breakeven Price to Cover, Total	1.66	1.85

Table 3.11:: Sensitivity analysis - estimated net returns above total cost in ponds with 2.47 cells/ha at varying fish selling price and feed costs (based on projected feeding).

	Price of Fish ($/kg)										
Feed Prices ($/Kg)	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6
0.36	-315	3,031	6,376	9,722	13,067	16,412	19,758	23,103	26,448	29,794	33,139
0.38	-1,437	1,908	5,254	8,599	11,944	15,290	18,635	21,981	25,326	28,671	32,017
0.40	-2,559	786	4,131	7,477	10,822	14,167	17,513	20,858	24,203	27,549	30,894
0.42	-3,682	-336	3,009	6,354	9,700	13,045	16,390	19,736	23,081	26,426	29,772
0.44	-4,804	-1,459	1,886	5,232	8,577	11,922	15,268	18,613	21,959	25,304	28,649
0.46	-5,927	-2,581	764	4,109	7,455	10,800	14,145	17,491	20,836	24,181	27,527
0.48	-7,049	-3,704	-358	2,987	6,332	9,678	13,023	16,368	19,714	23,059	26,404
0.50	-8,172	-4,826	-1,481	1,864	5,210	8,555	11,900	15,246	18,591	21,937	25,282
0.52	-9,294	-5,949	-2,603	742	4,087	7,433	10,778	14,123	17,469	20,814	24,159
0.54	-10,417	-7,071	-3,726	-380	2,965	6,310	9,656	13,001	16,346	19,692	23,037
0.56	-11,539	-8,194	-4,848	-1,503	1,842	5,188	8,533	11,878	15,224	18,569	21,915

Chapter 4

Discussion

4.1 Production

The production statistics realized during the trial were lower than expected. However, the projected production from 2.47 IPRS cells/ha is much greater than that typically produced from the trials ponds. As was mentioned earlier the two trial ponds, in which the IPRS cells were placed, were selected for their poor production in previous years. It is difficult to estimate annual production on a per pond basis due to the multiple-batch system employed but personal conversations with the farm manager indicated that 5,500 – 6,750 kg/ha was typical for these ponds. The projected production of 8,589 - 10,895 kg/ha with 2.47 IPRS cells per ha indicate that the potential for a large increase in production over the current pond production model is possible. This is supported by the fact that Pond A7 reached over 6,400 kg/ha and Pond A15 over 11,000 kg/ha when the production from the open pond is included. It must be mentioned however, that Pond A15 was stocked in the beginning of the trial with a number of large fish.

The difference in production numbers seen from the two ponds likely gives some insight into what production would be seen if a mixture of IPRS and multi-batch open pond culture were employed. If the study was extended another year it is likely that the large number of larger but below-harvest size fish in Pond A7 would reach harvest size and lead to a production level similar to what was seen in Pond A15 this year. Likewise, the lack of larger fish in Pond A15 would likely lead to reduced production in Pond A15 the following year. It should be noted that neither the total production or projected production from 2.47 IPRS cells/ha reached that seen with intensive aeration systems such as split ponds (Brune et al. 2012). This could be due to several shortcomings of the trial system.

As was mentioned the ponds selected were already known to have lower production than that seen on typical catfish ponds on this farm and in this region. There are additional factors that could have also contributed to reduced production. One of these is that the IPRS relies on a system design that enhances water circulation and mixing. Several of the protocols recommended to promote this movement were not adhered to in this study. The first of these is placement of the IPRS systems perpendicular to the longest levee of the pond. This allows the exiting water to travel the longest distance before meeting any barrier (levee). In this study the systems were placed facing along the shorter levees of the pond by the farm manager. Another design flaw of the system related to placement was the proximity and orientation of the raceways. It is recommended that the raceways be placed parallel to the levee. In this case they were oriented perpendicular to the levee with the inflow less than 8 meters from the edge of the pond. It was noted on several occasions that there were eddies forming from the water rapidly turning around the outside of the raceways as it was pulled into the inflow. This led researchers to hypothesize that there may have been some restriction of water flowing into the raceways by the narrow gap between raceway and pond bank.

The observation of water rapidly flowing around the sides of the raceway also indicated another problem in the way the system design was not adhered to by farm management. It is recommended that a baffle “wall” system be in place extending from the IPRS outflow to at least 2/3 of the distance of the pond and reaching from the pond bottom to just above water level. This baffle “wall” is meant to force water to circulate throughout the entire pond before returning to the inflow of the raceway. If not installed the water flow can return to the IPRS unit in a shortened path and this prevents the biological “cleaning” of the water before it is reused. It was also recommended that an additional water mover be added between the baffle and levee opposite the IPRS. This would further increase the mixing in the pond and the accompanying biological processing as described by Busch (1980). Figure 4 from Chappell (Auburn University) shows the proper IPRS raceway orientation within the pond and a correctly positioned baffle “wall” system.

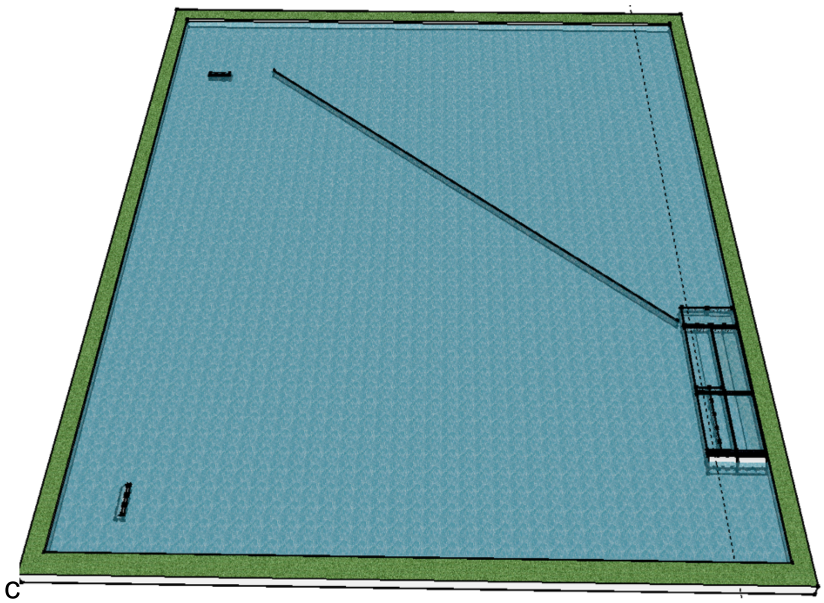

Figure 4.1. Illustration of the proper orientation of an IPRS within a pond including the diagonal baffle wall and two auxiliary whitewater units.

The low IPRS cell density along with having fish stocked in the open pond at the same time may have also been detrimental to the study trial. In Pond A15 an especially large standing crop of fish was present throughout the trial. Standing crops much larger than were present in this study have been shown to be sustainable in previous studies (Tucker and Kingsbury 2010), however large inputs of electricity in the form of oxygen maintenance are required. In this case the usual paddlewheel aeration was employed only in emergency duty and the duty of oxygen addition was left largely to the IPRS raceways. In a proper system this same or greater amount of fish could possibly have been raised but an additional four IPRS raceways and accompanying watermoving units would have to been installed to properly maintain oxygen levels. It is the researchers' belief that this high standing fish crop with low aeration likely lead to the elevated ammonia levels witnessed in Pond A15. Had these high ammonia levels been avoided it is possible production statistics from Pond A15 would have been more favorable.

Another issue that may have led to the lower than expected production numbers during the trial was the below recommended feeding. Feeding was conducted to near satiation for the majority of the study however, during the last 3.5 months of culture, feeding was greatly reduced. This was due to the farmers' belief that the *Aeromonas* disease outbreak was caused by overfeeding. No research has been conducted on the linkage between the percentage bodyweight feeding and *Aeromonas* making it is difficult to determine whether this was the case. It is common practice on this farm to reduce feeding during a disease event. The inconsistency in this case was the fact that feeding remained well below recommended levels long after the fish ceased to show signs of disease. Furthermore, Pond A7 saw no mortalities from this event but feeding was reduced similar to Pond A15. It can be seen from the projected production that had a modest 1.5% bodyweight feeding regimen been implemented the production would have been greatly increased.

Another aspect of the increased feed would be the assumed ability of fish to reach harvest size. In the trial approximately 57% of the fish harvested were large enough to send for processing. The majority of fish remaining were near harvest size with only 2.5% being less than 225 g. It is expected that the increase in feeding during the last phase of feeding would allow these fish to reach harvest size.

Based on conversations with farmers operating IPRS systems a stocking density of approximately 250 fish/cubic meter is recommended. The study farm decided to surpass this density and stock 268 fish/cubic meter. Differences in the farm and hatchery samples indicated that the true stocking rate may have been closer to 286 fish/cubic meter. However, the recommended stocking rate is based on field observations and not scientific studies so the actual optimal density is not known. Additionally, the recommendation of stocking number is made based on the assumption of fish reaching a weight of 0.68 kg before harvest. The fish in this study did not reach 0.68 kg in size making it difficult to speculate on if there were any negative effects from this perceived over-stocking.

4.2 Economics

The trial system tested did not result in a profit however, this was expected due to the low IPRS raceway density placed in the pond in this trial. After the IPRS raceway numbers were scaled to reflect the recommended IPRS cell density the system was more profitable. In the study by Courtwright the average profitability of all farms studied during 2012 was -$1,932/ha. After substituting 2012 prices and calculating receipts for fish sold and costs for feed, electricity, harvest, transport, interest on operating capital and fixed costs the projected profitability of Pond A7 and Pond A15 was $1,059/ha and -$771/ha respectively, assuming 2.47 cells/ha without adjusting for feeding, Table 4.1. If the feeding was adjusted as previously described the projected profitability increases to $6,306/ha for Pond A7 and $2,072/ha, Table 4.2.

An additional benefit of IPRS technology is the possibility of polyculture in the remainder of the pond not being occupied by the raceways. Polyculture has two possible benefits for aquaculture. It both allows for additional income from secondary species, and can improve water quality by stocking species that will consume the algal growth produced from the waste of the primary species. Turker et al. (2003) showed that nile tilapia will graze on both green algae and cyanobacteria. Cyanobacteria are not desirable in aquaculture ponds because of their potential to release harmful toxins when stressed. Additionally, by removing algae the average age of algae present is reduced which increases the oxygen production and algal growth which in turn increases the removal of waste. In the study by Brown et al. (2011) the additional production from the co-culture of other species reduced the total price of production from $1.90/kg to 1.69/kg. Clearly, co-cultured fish species can greatly improve the economics of the system and should be included in future experiments.

A common question related to the IPRS system is the cost of electricity associated with constant (24/7) aeration. The cost of aeration in the experimental system was 10% of the total cost of production. This is 4.4% higher than the 5.6% of total cost seen on the average Alabama farm (Courtwright 2012). When production was projected to 2.47 IPRS cells/ha this expense increased to 13% of total costs.

4.3 Future Developments

One of the primary benefits of IPRS systems is the concentration of fish that allows for effective waste removal and therefore increased loading capacity in ponds. To this point, no effective waste removal system has been designed for in-pond raceways. If increases in production are going to be achieved one of the limiting factors will be ammonia and nitrite. One method for dealing with this is through increased water processing by using water mixing and aeration devices as described earlier. Another is through the removal of fish waste. If a suitable method for fish waste removal is developed, the total fish production quantity could be increased further.

The design of the IPRS is new and rapidly evolving. Continued research and development should lead to reduced costs and increased longevity. Furthermore, increased usage could lead to the development of improved methods that could reduce labor and increase fish survival.

Chapter 5

Conclusion

One of the goals of this study was to determine the effect and necessity of IPRS screen cleaning. As was mentioned there is an increase in labor associated with the IPRS. A portion of this is the bi-weekly cleaning of screens. It was determined that cleaning of screens does have a large effect on the water velocity inside the IPRS system and therefore water quality. No study was done to determine the optimal cleaning frequency. With that said it is recommended that cleaning continue on a bi-weekly basis and that trials be run to investigate the minimal amount of cleaning necessary to maintain water quality at sufficient levels within the unit.

The results of this study after being expanded to indicate production expected for 2.47 IPRS cells/ha were able to show the production and economic potential of this system. The primary benefit seen from this study is the greatly improved FCR over traditional pond culture of catfish. The improvements in FCR are likely due to an increased feeding visibility and improved oxygen conditions for the fish. It will be important in the future to operate experiments that investigate the production capacity and feed conversion capacity of these systems when operated at full scale. It is believed that the additional water/oxygen mixing and aeration from water moving units will allow the ponds to assimilate the additional fish production wastes without negative effects on the water quality. This belief needs to be tested. It will also be important in future trials to push the system to determine the maximum density of cells. It has been estimated that 2.47 IPRS cells/ha is a reasonable unit density but no trials have been conducted to test the production from 2 vs. 2.5 vs. 3 IPRS cells/ha.

There are drawbacks to the use of these systems that are worth mentioning. First is the increase in labor required to properly operate the system. Adequate labor in the rural region of the west Alabama catfish industry is scarce. More people are moving to urban areas and those remaining in the rural areas are less inclined to take a job that involves manual labor outdoors during the warmest seasons of the year. Additionally, the high startup cost of building the IPRS compared to already existing ponds makes it difficult for owners to begin using the systems. In the future it will be important to streamline the operation of these systems to minimize labor inputs from the farmer. It will also be important to develop cheaper/better materials that will allow for a cheaper startup and longer lifespan of the system.

Another adjustment that must be made when implementing IPRS technology is a change in management technique. The operation and principles of IPRS usage is different than that of an open pond aquaculture operation and it is important that managers understand the principles that allow for the increased production and profitability. There is a learning curve associated with the proper operation of an IPRS. It is important that managers do not operate the system based on the principles that drive open pond catfish production. Currently, a production manual is being written that would help to outline some of the principles and operations of the systems to help facilitate this learning.

There are several additional benefits of the IPRS technology that are not completely understood as of yet and should be investigated in further studies. First is the effect of a constant IPRS flow of water on the problem of off-flavor in catfish fillets. Studies have shown that increased aeration helps to reduce off-flavor in catfish fillets (Courtwright 2013, Torrans 2005) and it is believed that this will continue to be the case with the IPRS but no studies have been done to confirm this.

The second is the effect of constant IPRS water flow on the fillet yield of catfish grown in raceway systems. The skin-on fillet yields seen with this study (61.7%) were significantly higher than those found for hybrid catfish by Bosworth et al. (2004); 53.3-54.1%. If higher fillet yields are achieved with the use of this technology, there would be an additional benefit to their use. A more in-depth study should be undertaken to determine if the difference in yield was caused by the IPRS dynamics.

Literature Cited

Arias, C.R., C. Wenlong, E. Peatman, Bullard, S. 2012. Catfish hybrid *Ictalurus punctatus* x *I. furcatus* exhibits higher resistance to columnaris disease than the parental species. Dis Aquat Organ 100(1): 77-81.

Blumenthal, G. 2013. Catfish industry analysis and consensus building. World Perspectives, Inc. Washington, D.C., USA.

Bosworth, B.G., W.R. Wolters, J.L. Silva, R.S. Chamul, and S. Park. 2004. Comparison of production, meat yield, and meat quality traits of NWAC103 line channel catfish, Norris line channel catfish, and female channel catfish X male blue catfish F1 hybrids. North American Journal of Aquaculture 66: 177-183.

Brown, T. W., Chappell, J. A., and Boyd, C. E. 2011. A commercial-scale, in-pond raceway system for Ictalurid catfish production. Aquacultural Engineering, 44: 72-79.

Brune, D. E., C. Tucker, M. Massingill, and J. Chappell. 2012. Partitioned aquaculture systems. Pages 308-340 in J. H. Tidwell, editor. Aquaculture production systems. Wiley-Blackwell Scientific Publications, Ames, Iowa.

Busch, C.D. 1980. Water circulation for pond aeration and energy conservation. Journal of the World Aquaculture Society 11(1-4): 91-101.

Chappell, J. A. 1979. An evaluation of twelve genetic groups of catfish for suitability in commercial production. Dissertation Auburn University.

Chappell, J.A. 2016. Personal Communication. Fisheries and Allied Aquacultures, Auburn University, AL.

Courtwright, C. 2013. Best Management Practices for West Alabama Catfish Production: Creating Profitability Through Efficiency, Consistency, and Quality. Auburn University Thesis.

Durborow, R. M., D. M. Crosby, and M. W. Brunson. 1997. Nitrite in Fish Ponds. Southern Regional Aquaculture Center. 462.

FAO. 2012. World Review of Fisheries and Aquaculture.

Fern, Micah. 2014. An economic comparison of three intensive fish production systems. Masters Thesis. Department of Fisheries and Allied Aquaculture, Auburn University, Auburn, Alabama, USA.

Hanson, T. R. and D., Sites. 2015. 2014 U.S. Catfish Database. Department of Agricultural Economics, Mississippi State University. http://www.agecon.msstate.edu/whatwedo/budgets/docs/catfish2014.pdf [accessed June 29, 2016].

Hargreaves, J. A. and C. S. Tucker. 2004. Managing Ammonia in Fish Ponds. Southern Regional Aquaculture Center. 4603.

Hawcroft, B. A. 1994. Development and Evaluation of an In-Pond-Raceway and Water Removal System. Master’s Thesis, Auburn University.

Hemstreet, B. 2010. An update on Aeromonas hydrophila from a fish health specialist for summer 2010. Catfish Journal, 24(4).

Holland, L. 2016. Comparing Economic Returns of Dissolved Oxygen Management in Commercial Catfish Production. Masters Thesis. Department of Fisheries and Allied Aquaculture, Auburn University, Auburn, Alabama, USA.

Hossain, M. J., D. Sun, D.J. McGarey, S. Wrenn, L.M. Alexander, M.E. Martino, Y. Xing, J.S. Terhune and M.R. Liles. 2014. An Asian origin of virulent *Aeromonas hydrophila* responsible for disease epidemics in United States-farmed catfish. mBio 5(3):e00848-14. Doi:10.1128/mBio.00848-14.

Morrison, J. R., W. L. Deavours, J. C. Jones and M. A. Tabb. 1995. Early Rearing of Channel Catfish Fry in Floating Raceways and Subsequent Survival in Ponds. The Progressive Fish-Culturist. 57:4, 292-296.

Parker, N.C. 1988. Floating raceway system can expand production of striped bass. United States Fish and Wildlife Service Research Information Bulletin No. 88-85, United States Department of Interior, Washington DC, USA.

Phan, L.T., Bui, T.M., Nguyen, T.T. Googley, G.J. Ingram, B.A. Nguyen, H.V., Nguyen, P.T., and Silva, S.D. 2009. Current status of farming practices of striped catfish, Pangasianodon hypopthalmus in the Mekong Delta, Vietnam. Aquaculture 296(3-4):227-236.

Sneed, K. E. and C. E. Cozort. 1959. An Inexpensive Experimental Spiral Raceway. The Progressive Fish-Culturist 21(2):80.

Snow, J.R. 1962. A comparison of rearing methods for channel catfish fingerlings. The Progressive Fish-Culturist 24 (3): 112-118.

Stewart, J. 2013. US catfish industry bleeding finally stops. Available: http://www.undercurrentnews.com/2013/07/03/us-catfish-industry-bleeding-finallystops/#.UjcieWR4baA. (Accessed June 15, 2016).

Torrans, E.L., 2005. Effect of Oxygen Management on Culture Performance of Channel Catfish in Earthen Ponds. North American Journal of Aquaculture 67: 275-288

Tucker, C. S. and S. K. Kingsbury. 2010. High-density split-pond systems offer high output, low maintenance. Global Aquaculture Advocate 13:64-65.

Turker, H., A. Eversole, D. Brune. 2003. Filtration of green algae and cyanobacteria by nile tilapia Oreochromis niloticus, in the Partitioned Aquaculture System. Aquaculture 215 (1-4): 93-101.

United States Department of Agriculture/National Agriculture Statistics Service (USDA/NASS). 2015. Catfish Production. United States Department of Agriculture, Washington, D.C., U.S.A. Available: http://usda.mannlib.cornell.edu/usda/current/CatfProd/CatfProd-01-30-2015.pdf

USDA. 2010. Catfish 2010 Part II: Health and Production Practices for Foodsize Catfish in the United States, 2009. USDA–APHIS–VS, CEAH. Fort Collins, CO. #595.0611

USDA, 2010. Catfish: Health and production practices for foodsize catfish in the United States. https://www.aphis.usda.gov/animal_health/nahms/aquaculture/downloads/catfish10/Cat10_dr_PartII.pdf

Yant D. R., R. O. Smitherman and O. L. Green. 1975. Production of hybrid (blue x channel) catfish and channel catfish in ponds. Proceeding Annual Conference Southeastern Association Game Fish Commissioners 29: 86-91.

Appendix A

Table A.4.1: Enterprise budget for 2.47 IPRS/ha producing hybrid catfish at a commercial farm in West Alabama in 2012 using data from Courtwright (2013).

Budget Parameter										
Pond				A7				A15		
Harvest Mass (kg)				29,430				24,036		
Growth Period (Months)				12				12		
	$/ Unit	Unit	#	$	$/ha	$/kg	#	$	$/ha	$/kg
Receipts*	2.16	kg	29,430	63,569	26,180	2.16	24,036	51918	21,382	2.16
Variable Costs										
Feed*	0.517	kg	46,095	23,831	9,815	0.81	42,672	22,061	9,086	0.92
Labor and Management*	13	$/hr	420	5,565	2,292	0.19	420	5,565	2,292	0.23
Fingerlings*	0.17	$/fish	29,832	4,922	2,027	0.17	32,352	5,338	2,198	0.22
Harvest and Transport*	0.05	$/kg	29,430	1,472	606	0.05	24,036	1,202	495	0.05
Energy*	0.09	$/kWh	101,268	9,114	3,754	0.31	101,268	9,114	3,754	0.38
Chemicals										
Formalin	2.12	$/L	352.2	747	308	0.03	117.4	249	103	0.01
Potassium permanganate	5.1	$/kg	74.7	381	157	0.01	24.9	127	52	0.01
Interest on Operating Capital*	10.0%	%	32,222	3,222	1,327	0.11	32,742	3,274	1,348	0.14
Total Variable Costs				**49,254**	**20,285**	**1.67**		**46,931**	**19,328**	**1.95**
Income Above Variable Costs				14,315	5,896	0		4,987	2,054	0.21
Total Fixed Cost (adjusted for 294 culture days)				11,743	4,836	0.40		6,859	2,825	0.29
Total Cost				60,997	25,121	2.07		53,789	22,153	2.65
Net Return Above Expenses				**2,572**	**1,059**	**0.09**		**-1,871**	**-771**	**-0.08**

	A7	A15
Breakeven Price to Cover, Variable	1.67	1.95
Breakeven Price to Cover, Total	2.07	2.24

Table A.4.2: Enterprise budget for 2.47 IPRS/ha producing hybrid catfish at a commercial farm in West Alabama in 2012 using price data from Courtwright (2013) and projected production based on increased feeding.

Budget Parameter										
Pond				A7				A15		
Harvest Mass (kg)				38,276				28,631		
Growth Period (Months)				12				12		
	$/Unit	Unit	#	$	$/ha	$/kg	#	$	$/ha	$/kg
Receipts	2.16	kg	38,276	82,676	34,050	2.16	28,631	61843	25,470	2.16
Variable Costs										
Feed	0.517	kg	56,748	29,339	12,083	0.77	47,666	24,643	10,149	0.86
Labor and Management	13	$/hr	420	5,565	2,292	0.15	420	5,565	2,292	0.19
Fingerlings	0.17	$/fish	29,832	4,922	2,027	0.13	32,352	5,338	2,198	0.19
Harvest and Transport	0.05	$/kg	38,276	1,914	788	0.05	28,631	1,432	590	0.05
Energy	0.09	$/kWh	101,268	9,114	3,754	0.24	101,268	9,114	3,754	0.32
Chemicals										
Formalin	2.12	$/L	352.2	747	308	0.02	117.4	249	103	0.01
Potassium permanganate	5.1	$/kg	74.7	381	157	0.01	24.9	127	52	0.00
Interest on Operating Capital*	10.0 %	%	36,387	3,639	1,499	0.10	34,851	3,485	1,435	0.12
Total Variable Costs				**55,620**	**22,907**	**1.45**		**49,953**	**20,573**	**1.74**
Income Above Variable Costs				27,056	11,143	1		11,890	4,897	0.42
Total Fixed Cost (adjusted for 294 culture days)				11,743	4,836	0.31		6,859	2,825	0.24
Total Cost				67,363	27,743	1.76		56,812	23,398	2.65
Net Return Above Expenses				**15,313**	**6,306**	**0.40**		**5,031**	**2,072**	**0.18**

	A7	A15
Breakeven Price to Cover, Variable	1.45	1.74
Breakeven Price to Cover, Total	1.76	1.98

Table A 3: Fixed Costs of farm operating 0.85 IRPS cells/ha from Wilson (2016).

	Unit	Cost/ unit	#	% to Pond	Cost	SV	Useful life	Depreciation	Average Inv.	% Interest on Inv.	% Annual Repairs	Repairs Cost
A. Capital Cost												
Land	$/ha	$4,860	3	100%	$14,580							
Raceways	$/cell	$6,000	2	100%	$12,000	$700	10	$1,130	$6,000	$600	5%	$600
Pond Construction	$/ha	$3,038	3	100%	$9,114		15	$608	$4,557	$456	1%	$90
Electric work	$	$600	5	100%	$3,000	$50	10	$295	$1,500	$150	5%	$150
Gravel	$/Load	$235	21	100%	$4,935		8	$617	$2,468	$247	1%	$25
Office	$	$30,000	1	1%	$300		15	$20	$150	$15	1%	$3
Shop	$	$80,000	1	1%	$800		15	$53	$400	$40	1%	$8
Tools and Equipment	$	$10,000	1	1%	$100	$25	10	$8	$50	$5	5%	$5
Subtotal (excluding land)				100%	$30,194			$2,772		$910		$881
B. Equipment												
Trucks, 1/2 ton	$	$22,000	2	1%	$440	$5	6	$73	$220	$22	17%	$73
Feed Truck (International 30000 gvw) $	$	$42,000	2	1%	$840	$5	15	$56	$420	$42	7%	$56
Feed Bins(20 ton)	$	$7,000	2	1%	$140		20	$7	$70	$7	5%	$7
Tractors(pump, bushhog)	$	$9,000	1	1%	$90	$15	12	$6	$45	$5	0%	0
Generators	$	$4,570	1	100%	$4,570	$500	15	$271	$2,285	$229	5%	$229
Aerators, 7.5 kW	$	$1,800	2	100%	$3,600		7	$514	$1,800	$180	20%	$720
PTO pump	$	$1,500	1	1%	$15		10	$2	$8	$1	10%	$2
Bush hog/mower	$	$4,000	1	1%	$40		10	$4	$20	$2	10%	$4
Monitoring System, Pentair	$	$971	5	100%	$4,855		10	$486	$2,428	$243	10%	$486
Computer and Electronic Equipment	$	$500	1	50%	$250		5	$50	$125	$13	0%	

Subtotal	$14,840	$1,468	$742	$1,576
Total	**$45,034**	**$4,240**	**$1,652**	**$2,457**

Table A.4. Fixed Costs of projected setup (2.47 cells/ha) In-Pond Raceway System at 10% interest derived from Wilson (2016)

Item	Unit	Cost/Unit	#	% to Pond	Cost	SV	Useful life	Depreciation	Average Inv.	% Interest on Inv.	% Repairs	Repairs Cost
A. Capital Cost												
Land	$/ha	$4,860	3	100%	$14,400							
Raceways	$/cell	$6,000	6	100%	$36,000	$700	10	$3,530	$18,000	$1,800	5.00%	$1,800
Pond Construction	$/ha	$3,038	3	100%	$9,000		15	$600	$4,500	$450	1.00%	$90
Electric work	$	$600	9	100%	$5,400	$100	10	$530	$2,700	$270	5%	$270
Gravel	$/Load	$235	21	100%	$4,994		7.5	$666	$2,497	$250	0.50%	$25
Office	$	$30,000	1	1%	$300		15	$20	$150	$15	1.00%	$3
Shop	$	$80,000	1	1%	$800		15	$53	$400	$40	1.00%	$8
Tools and Equipment	$	$10,000	1	1%	$100	$25	10	$8	$50	$5	5.00%	$5
Subtotal(excluding land)				100%	56,594			$5,407		$2,830		$2,201
B. Equipment												
Trucks, 1/2 ton	$	$22,000	3	1%	$660	$5	6	$109	$330	$33	17%	$110
Feed Truck(International 30000 gvw)	$	$42,000	2	1%	$840	$5	15	$56	$420	$42	7%	$56
Feed Bins(20 ton)	$	$7,000	2	1%	$140		20	$7	$70	$7	5%	$7
Tractors(pump, bushhog)	$	$9,000	1	1%	$90	$15	12	$6	$45	$5	0%	$-
Generators(20 KVA)	$	$4,570	0.5	100%	$2,285	$500	15	$119	$1,143	$114	5%	$114
Aerators, 7.5 kW	$	$1,800	2	100%	$3,600		7	$514	$1,800	$180	20%	$720

PTO pump	$	$1,500	1	1%	$15	10	$2	$8	$1	10%	$2
Bush hog/mower	$	$4,000	1	1%	$40	10	$4	$20	$2	10%	$4
Monitoring System, Pentair	$	$971	7	100%	$6,797	10	$680	$3,399	$340	10%	$680
Computer and Electronic Equipment	$	$500	1	50%	$250	5	$50	$125	$13	0%	$-
Subtotal					$14,717		$1,547		$736		$1,692
Total					**$71,311**		**$6,953**		**$3,566**		**$3,893**

Figures:

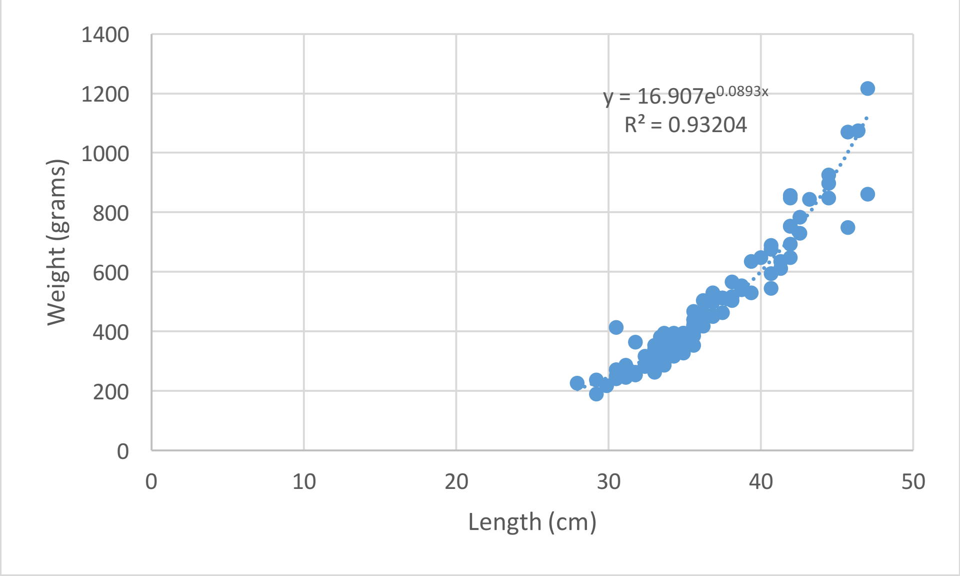

Figure A.1. Length-weight distribution of harvested hybrid catfish from two raceway cells in the study IPRS units located in Pond A7, West Alabama, 2015.

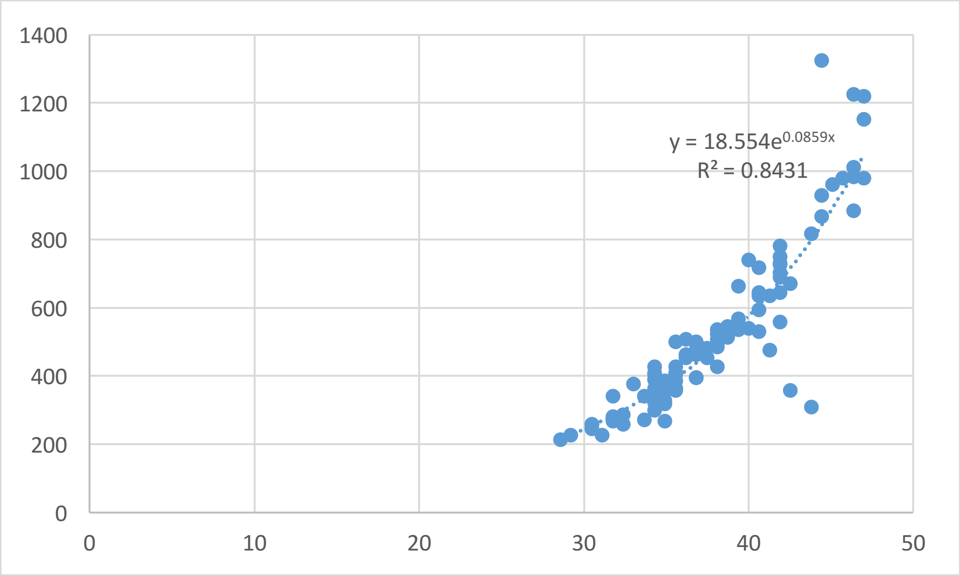

Figure A.2. Length-weight distribution of harvested hybrid catfish from two raceway cells in the study IPRS units located in Pond A17, West Alabama, 2015